

Primary Pre-Service Teachers' Understanding of STEAM Education Through Lesson Planning

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A STEAM Program was implemented in teacher education to prepare primary pre-service teachers to develop lesson plans that take full advantage of the interdisciplinary connections between science and mathematics topics. In this paper we describe how primary pre-service teachers' perspectives about STEAM pedagogy evolved through a science and mathematics module. Data collection consisted of pre-service teachers' assignments through STEM activities, interviews, and questionnaires. Overall, findings support the notion that the program had a positive impact on pre-service teachers' understanding about STEAM approach.

Keywords: Lesson plans, STEAM education, teacher education

Introduction

STEM (Science, Technology, Engineering, Mathematics) education movement emerged about 30 years ago in the United States with the purpose of promoting students' interest in these disciplines, driven by the need to prepare the STEM workforce to address urgent contemporary challenges (Kelley & Knowles, 2016). Research suggests that students should be involved in carrying out STEM activities, according to an integrated approach, from the earliest levels of schooling (Dejarnette, 2012). In recent years, a broader approach has been advocated that includes the articulation of STEM with other curricular areas (arts, languages, history, etc.), commonly known by the acronym STEAM (Quigley & Herro, 2016; Yakman, 2012).

In this context, a STEAM program was developed in teacher education to prepare primary pre-service teachers (PSTs) to create and use STEAM lessons that take full advantage of the interdisciplinary connections between science and mathematics topics. The goal of the current study is to investigate how primary PSTs develop STEAM lessons during a science and mathematics module and their attitudes and perspectives about integrated STEAM approach.

Theoretical Background

Various definitions of STEM education coexist in the literature, causing ambiguity in the interpretation of the term (English, 2016) and complicating its

application in the classroom (Martín-Páez et al., 2019). Thibaut et al. (2018), conducted an extensive literature review on STEM integration (iSTEM), based on social constructivist perspective on learning, and presented a framework encompassing five fundamental principles. These principles—integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning—articulate the foundational practices that underlie integrated STEM education. Firstly, the explicit integration of STEM content is emphasized by Thibaut et al. (2018), aiming to facilitate the development of students' knowledge and skills across diverse STEM disciplines. The proposed model underscores inquiry-based learning as a pivotal principle within the STEM integrative approach, aligning with a teaching methodology long advocated in science education (e.g., Bybee, 2006). This instructional practice is particularly associated with early education levels, leveraging children's inherent curiosity and their propensity to question the world around them (Greenwood et al., 2022). The iSTEM model also incorporates design-based learning, encouraging the integration of engineering design as a foundation for connecting with mathematics and/or science content. This approach is recommended for early exposure to students (Difrancesca et al., 2014; Guzey et al., 2016; Shalali et al., 2017). Design-based learning involves problem formulation or identification, planning of solutions, and the creation of models, prototypes, or other products addressing the identified problem (Guzey et al., 2016). Another significant aspect highlighted by Thibaut et al. (2018) is that STEM education fosters student involvement in addressing open-ended and real-world challenges within a compelling context (Shahali et al., 2017). Lastly, collaborative learning is identified as a distinctive feature of the STEM approach in the proposed model.

In recent years, literature has increasingly emphasized a more comprehensive pedagogical approach that incorporates non-STEM disciplines (Yakman, 2012; Quigley et al., 2017; Aguilera & Ortiz-Revilla, 2021). This approach arises from concerns about the lack of creativity and innovation in recent college graduates in the United States (Land, 2013). The seamless integration of STEM subjects with other fields, such as languages, social sciences, and arts, is termed STEAM by authors like Quigley et al. (2017), who define it as a transdisciplinary learning process. According to Quigley et al. (2017), the distinction between the STEM approach and STEAM lies in the intentional inclusion of the arts in the latter, whereas the former merely advocates for its inclusion.

Research focused on the impact of the STEAM approach in primary education has indicated highly positive results in terms of students' competences in the covered subjects (Bassachs et al., 2020), attitudes (Dejarnette, 2012) and their motivation (Lage-Gómez & Ros, 2021). Nevertheless, for the success of STEM or STEAM education in primary settings, there is a need to establish teacher

education programs that not only impart knowledge about inquiry but also instill the confidence to apply this methodology (Kim & Bolger, 2017). Moreover, research has shown that primary teachers with limited subject knowledge and pedagogical content knowledge (PCK) tend to develop less favorable attitudes towards science and have lower confidence in teaching science topics (Gresnigt et al., 2014). As a result, they allocate less time to its instruction, and employ more traditional teaching approaches.

The absence of a consensus on a shared definition of STEM integration underscores the pressing need to formulate a conceptual framework for STEM education within primary teacher education (Hourigan et al., 2021). Hence, it is recommended that teacher education goes beyond focusing solely on STEM areas, affording PSTs the opportunity to develop STEAM activities aligned with an integrated approach (Correia & Baptista, 2022; Kim & Bolger, 2017).

Methods

This study used a mixed-methods research design to investigate the effect of a STEAM program on PSTs understanding about STEAM pedagogy. Additionally, the study focused on their ability to develop STEAM lessons according to an integrated approach. The participants were primary PSTs studying in a Portuguese higher education institution, attending the last year of a teacher education program. The study sample was composed of 24 students enrolled in a science and mathematics module, within a methods course, who had no prior experience planning STEAM lessons.

For eight weeks, the PSTs performed several STEAM activities, learned about the theoretical background behind STEAM education, based on iSTEM model (Thibaut et al., 2018) and developed STEAM lesson plans. The PSTs were introduced to the topics listed in Table 1 during the module, over a total of 40 hours. After completing the module, PSTs had the opportunity to develop and implement STEAM lesson plans, for the 3rd and 4th grades of primary school, during five weeks of teaching practice.

Table 1. Analysis of PSTs lesson plans according to the iSTEM model (Thibaut et al., 2018).

Topics	Number of hours
Science and mathematics curriculum in primary education	5
The benefits of science education in primary education	
Social constructivism in science education	
Development of 21st-century skills	5
Collaborative learning	
Problem and project-based learning	
Hands-on activities	10
Inquiry-based learning	
5E-instructional model (Bybee et al, 2006)	
Assessment in mathematics and science education	5
Integration of technology	5
Interdisciplinary approach	10
STEAM education	

A questionnaire was applied at the beginning and at the end of the semester that was adapted from a validated instrument developed by Mahoney (2010) and later modified by Kim and Bolger (2017). Some open questions were added to the post-questionnaire for PSTs to express their opinion on the development of STEAM activities and the experiences they had in the context of teaching practice. For quantitative data treatment, the sample size considered the 20 participants who answered both questionnaires. To examine the qualitative data obtained from the open-ended questions, we devised a set of categories to delineate the prevailing themes in the responses through coding analysis. Subsequently, each response underwent coding, being assigned one or more categories, as certain responses encompassed multiple ideas that aligned with distinct categories.

Findings and Discussion

Pre-Service Teachers' STEAM Lesson Plans

Each group of PSTs had to design a STEAM lesson plan and had the opportunity to perform three STEAM activities. During the process, the PSTs received feedback on their work, to introduce improvements and reach a final version that effectively integrates the principles of a STEAM-integrated approach. These discussions offered insight to the instructors (the authors), who reoriented the support provided accordingly. The results attained concerning the analysis of lesson plans were summarized, in accordance with the predetermined categories on Table 2.

Table 2. Analysis of PSTs lesson plans according to the iSTEM model (Thibaut et al., 2018).

Category	Instructional Practices				
	S	T	E	A	M
Integration of STEAM content	G1, G2, G3, G4, G5, G6, G7	G1, G2, G3, G4, G5, G6, G7	G3, G5, G6, G7	G2, G4, G5, G7	G2, G4, G5, G6, G7
Problem-centered learning	G1, G3, G4, G5, G6, G7				
Inquiry-based learning	G1, G2, G3, G5, G6				
Design-based learning	G3, G5, G6, G7				
Colaborative learning	G1, G2, G3, G4, G5, G6				

Some features of the iSTEM model are more common in primary PSTs’ lesson plans. In most of the lesson plans, students work collaboratively to solve open-ended and real-world problems in inquiry based-learning activities, and curricular integration between science and technology is more frequent in the lesson plans. However, in most lesson plans, the role of technology was not limited to watching a video. In fact, many PSTs not only highlighted, in their reflections, the importance of including technology, but also the use of it to articulate content from different domains. The second most common benefit of STEAM approach the PSTs focused on was collaborative learning, also considered a strength in Correia and Baptista’s (2022) study. Another aspect that emerged was that in all the lesson plans, the same attention was not applied to two or more STEM disciplines, although in most cases, there are strong connections between the contents of different disciplines. there was an emphasis on science and mathematics, which is usual in primary education (Gresnigt et al., 2014), but it can lead to a disregard of the component of engineering and design process (DiFrancesca, 2014). In fact, it was found that only four groups took advantage of the context provided by Engineering to learn science and/or mathematics content (Shahali et al., 2017). Another aspect that stood out in the results was the fact that only four lesson plans included arts and, similarly to Quigley and Herro’s study (2016), most of those connections did not go beyond design arts.

Pre-Service Attitudes And Perspectives About An Integrated Steam Approach

Analyses of questionnaires and interview transcripts provided insight into their perspectives about STEAM approach (Interest in STEAM activities, motivation to develop STEAM activities, valuing education with STEAM and deepening

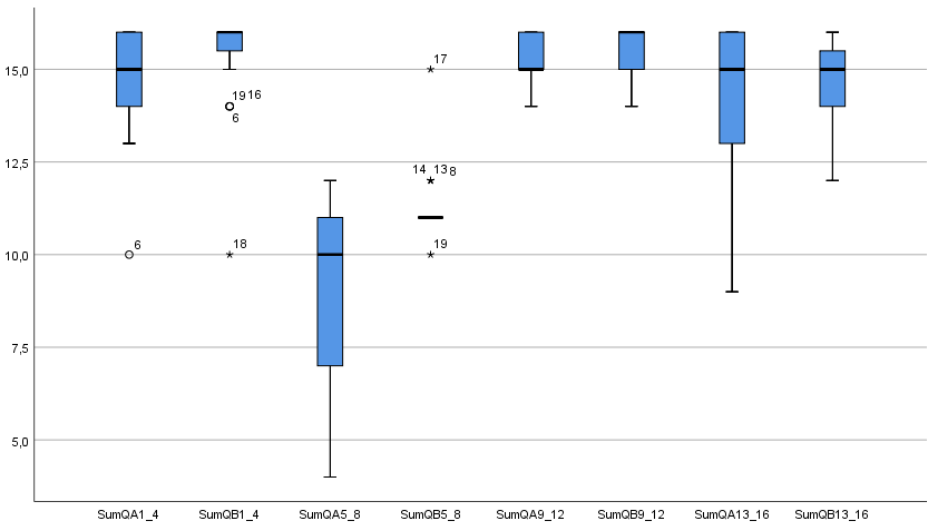
knowledge about STEAM). Summaries of interest variables are presented as mean±standard and available in table 3, as well as more detailed results like minimum and maximum values of the sums of the variables under study.

Table 3. Summary measures of four variables analyzed in pre-test (QA) and post-test (QB).

Categories		N	Minimum	Maximum	Mean	Std. Deviation
Interest in STEAM activities	SumQA1_4	20	10,0	16,0	14,800	1,5079
	SumQB1_4	20	10,0	16,0	15,350	1,4609
Motivation to develop STEAM activities	SumQA5_8	20	4,0	12,0	9,100	2,5319
	SumQB5_8	20	10,0	15,0	11,300	,9787
Valuing education with STEAM	SumQA9_12	20	14,0	16,0	15,150	,7452
	SumQB9_12	20	14,0	16,0	15,550	,6863
Deepening knowledge about STEAM	SumQA13_16	20	9,0	16,0	14,200	1,8806
	SumQB13_16	20	12,0	16,0	14,800	1,0052

The motivation to perform STEAM activities was the dimension that had the greatest impact with (Mean 9.1 and SD 2.53 in QA; Mean 11.3 and SD 0.98 in QB). These measurements are consistent with the measurements of the extreme and quartile diagram (figure 1) since in QB there was very little variability in the data. Descriptive measures of the data suggest that participants have come to value the STEAM approach much more. In fact, although the average of the sum of the indicated levels is slightly higher in QB (Mean 15.55), there is a lower deviation after the STEM program (SD 0.68). The extreme and quartile diagrams (Figure 1) allow visualizing how data behave as well as its variability in the two moments (QA and QB). The extreme and quartile diagrams (Figure 1) allow visualizing how data behave as well as its variability in the two moments (QA and QB).

Figure 1. Comparative diagram of extremes and quartiles for the four dimensions.



The comparison of the variables in the two moments (beginning and at the end of the semester) was performed through a Wilcoxon test, used for paired samples (Table 4). The first three dimensions showed a positive evolution with a significant Wilcoxon test ($p\text{-value} < 0.05$). However, in the fourth dimension, students did not show statistical differences between the two moments ($p\text{-value} = 0.227$), meaning that the developing lessons positively influenced pre-service teacher attitudes about the STEAM approach mainly in what concerns motivation and valuing, being inconclusive about deepening PSTs' STEAM knowledge. As the PSTs engaged in planning STEAM lessons, they began to see more of the advantages of this integrated approach. The experience of developing STEAM lesson plans within the science and mathematics module impacted PSTs' attitudes positively toward the STEAM approach (Kim & Bolger, 2017).

Table 4. Test statistics used to compare samples.

Test Statistics ^a				
	SumQB1_4 - SumQA1_4	SumQB5_8 - SumQA5_8	SumQB9_12 - SumQA9_12	SumQB13_16 - SumQA13_16
Z	-1,992 ^b	-3,124 ^b	-2,309 ^b	-1,208 ^b
Asymp. Sig. (2-tailed)	,046	,002	,021	,227

a. Wilcoxon Signed Ranks Test | b. Based on negative ranks.

In the final questionnaire, PSTs answered open-ended questions about the STEAM approach and the development of STEAM activities according to their

experience. From the analysis of PSTs' responses to this open questionnaire, that integrated PSTs' attitudes post-questionnaire, emerged a set of categories (Table 5).

Table 5. PSTs' perspectives about an integrated STEAM approach in the open-ended questions added to the post-questionnaire.

Categories	PSTs' responses and frequency
Difficulties in designing a STEAM activity	Interdisciplinarity (11), developing the activity guide (7), including technology (2), including engineering (2), classroom practice (1)
Challenges associated with classroom practice	Require, from the teacher, greater ability to promote interdisciplinarity (6) Need to spend more time (5) More demanding resource management (4) Require greater autonomy from students (2)
Benefits associated with STEAM approach	More active role of students (10) Interdisciplinarity/meaningful contexts for students (8) Knowledge learning and skills development (5) Collaborative work (2)

During the program, all PSTs planned STEAM lesson plans, but only 65% of them experienced the implementation of a STEAM activity. When asked about the reasons, 35% mentioned that they had to comply with the planning of their cooperating head teacher, who did not include any STEAM activities in their plans. Some also cited time management issues or existing projects in the school. These findings suggest that although PSTs have developed a positive attitude towards the STEAM approach, planning activities in the training module may not be enough to ensure implementation in the classroom. Therefore, it is necessary to provide additional support and closely monitor future teachers' practices to prepare them for the challenges of implementing STEAM activities.

Comparing PSTs' answers in the final questionnaire with their reflections regarding the benefits and challenges associated to STEAM approach, there are many similarities. For instance, PSTs highlighted interdisciplinarity as the main benefit and challenge of STEAM activities. Another interesting result is the fact that the teachers, perhaps due to the anonymity of the questionnaire and the absence of guidelines, unlike the reflective writing assignment, distanced themselves from STEAM approach features and pointed out difficulties related to the amount of effort, expertise and time required for the preparation of this type of learning activities. These findings are close to those obtained by Kim and Bolger (2017), specifically the fact that PSTs remained concerned about their ability to implement STEAM lessons.

The content analysis of reflective written assignments (Table 6) exhibits a solid

knowledge of the participants of the features of iSTEM model (Thibaut et al., 2018). PSTs mentioned how much they valued the opportunity to experience planning and implement STEAM activities by identifying positive aspects such as the knowledge about the characteristics of the STEAM approach (“Learning a new methodology in the classroom and designing a way of collaborative work involving several areas STEAM.” (APST2, QB)), as well as the development of their self-confidence to implement STEAM activities in their future practice (“It was great to give us security in developing STEAM activities in the future.” (APST15, QB)). Nevertheless, about 35% did not experience the implementation of a STEAM activity mentioning reasons about complying with the planning of the cooperating head teacher.

Table 6. PSTs’ perspectives about an integrated STEAM approach in the reflective writing assignments.

Categories	PSTs’ responses and frequency
Challenges	Integration of STEAM content (11) Students’ interests and difficulties (10) Inquiry-based learning (6) Assessment (1)
Benefits	Interdisciplinarity (21), Collaborative learning (19), Inquiry-based learning 15), Focus on real-world problems (14), Critical thinking (13), Creativity (9), Integration of non-STEM content (8), Design-based learning (8), Students’ interests and needs (7), Computational thinking (5), Students’ positive emotions (1)

The analysis of the collected data from the interviews suggests that future teachers reaffirm difficulties associated with planning a STEAM activity and the challenges associated with teaching practice, namely the promotion of interdisciplinarity, the integration of STEAM areas such as Technology or Mathematics and consequently the development of a script that has meaning for PSTs where STEAM areas are included in a coherent whole.

What may be more difficult is to faithfully respect the criteria of these activities and interconnect them in a coherent way, that is, in a way that makes sense. (...) What may be more difficult may be connecting everything coherently. (Interview - PSTs 13 and 14)

Another aspect identified as a difficulty associated with planning is knowledge of technological resources. Although PSTs recognize that throughout their training they contact with immense digital resources, they feel that, when planning STEAM activities, the broader this knowledge, the easier it is for them to promote better learning and incorporate technology.

A difficulty is also the limited knowledge that we have, that the teacher may have, about resources, which conditions the way we develop activities. The

more (resources) we know, the better we can enhance activities and not be so limited, in terms of technology, for example. With the classes we learn about many resources and materials and of course this helps to create better and more consistent activities, but we feel that this difficulty emerges when planning. (Interview - PSTs 7 and 8)

The interviews also provide evidence that PSTs acknowledge the interconnected benefits and challenges associated with the STEAM approach. Specifically, they recognize its role in promoting interdisciplinarity and highly value collaborative work as an active learning process for both teachers and students.

The collaborative work it provides, encourages students to engage in debates, discuss challenges, confront difficulties, and collectively address problems that may arise. Working together, they strive to overcome obstacles, reaching consensus through thoughtful debate and questioning. This dynamic approach transforms the learning process into a more active and participatory experience, although occasional guidance from the teacher may be necessary. (Interview - PSTs 11 and 12).

In what concerns to the benefits of STEAM approach, PSTs found that the integration of content from different areas was the most important feature, although the interdisciplinarity between science and mathematics is more explicit in the lesson plans in terms of learning objectives and the contents covered.

Conclusions

Planning STEAM activities was a challenging task for the PSTs, especially integrating content from different domains. Despite the growing confidence of the PSTs to develop STEAM lesson plans as a result of their participation in a science and mathematics module, supported by the statistical analysis of the questionnaires, qualitative analysis also revealed that they were still concerned about their ability to design and implement STEAM activities. The analysis of the lesson plans designed by the PSTs focused on how the iSTEM model was incorporated. They made a real effort to foresee almost all model features; nevertheless, engineering and design process played a very small role or were completely absent. The same applies to the integration of the arts. Therefore, more attention should be paid in preparing teacher candidates at the primary level to integrate engineering (DiFrancesca et al., 2014) and to go beyond the integration of digital/design arts (Quigley & Herro, 2016). Although students expressed confidence in implementing STEM activities in primary school, not all PSTs could implement their lesson plan in practice, so it is imperative to progress with this experience to another stage that involves PSTs in planning STEAM activities and their implementation in the context of professional practice. Teacher education should, therefore, continue to move towards providing more practice situations where future teachers implement STEAM

activities and acquire experience and in contexts where this type of work is a reality.

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